Do recent supernovae Ia observations tend to rule out all the cosmologies?

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Abstract

Dark energy and the accelerated expansion of the universe have been the direct predictions of the distant supernovae Ia observations which are also supported, indirectly, by the observations of the CMB anisotropies, gravitational lensing and the studies of galaxy clusters. Today these results are accommodated in what has become the *concordance cosmology*: a universe with flat spatial sections $t =$ constant with about 70% of its energy in the form of Einstein's cosmological constant Λ and about 25% in the form of dark matter (made of perhaps weakly interacting massive particles). Though the composition is weird, the theory has shown remarkable successes at many fronts.

However, we find that as more and more supernovae Ia are observed, more accurately and towards higher redshift, the probability that the data are well explained by the cosmological models decreases alarmingly, finally ruling out the concordance model at more than 95% confidence level. This raises doubts against the *'standard candle'*-hypothesis of the supernovae Ia and their use to constrain the cosmological models. We need a better understanding of the entire SN Ia phenomenon in order to extract cosmological consequences from them.

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1. Introduction

The history of cosmology has probably never witnessed such upheavals as evidenced in the past few years, which are primarily due to the observations of distant supernovae (SNe) of type Ia. Many colourful exotic models have been speculated, which claim to provide satisfactory explanation to these observation. It is generally believed that the distant SNe Ia observations predict an accelerating expansion of the universe powered by some hypothetical source with negative pressure generally termed as *'dark energy'*. The simplest and the most favoured candidate of dark energy is a positive cosmological constant Λ, which is though plagued with the horrible fine tuning problems. This has led a number of cosmologists to resort to scalar field models of evolving dark energy, which can produce negative pressure for a potential energy-dominated field and cause the scale factor to accelerate at late times by violating the strong energy condition. While the scalar field models enjoy considerable popularity, they have not helped us to understand the nature of dark energy at any deeper level.

Though the idea of the accelerating expansion and dark energy in the framework of Einstein's theory is a prediction of the first generation of SNe Ia data, however as more and more accurate data get accumulated, the fit to the cosmological models worsens successively and the recent observations, taken at their face value, seem to rule out all the cosmologies at fairly high confidence levels! This will be shown in the present paper. It may be noted that in our goodness-of-fit analysis, we include only those observations which, unlike the SNLS observations, have already included the intrinsic dispersion of the SN absolute magnitude in their error bars. The SNLS data are not suitable for a goodness-of-fit analysis, as we shall see later.

It should be noted that the precise measurements of the temperature anisotropies of the CMB made by the WMAP experiment [1], which appear to offer the most promising determination of the cosmological parameters, are often quoted as providing a direct evidence for an accelerating universe, which is though not quite correct. The standard interpretation of the WMAP constraints may be misleading, as it relies on the assumption of the power law spectrum. Blanchard et al. [2] have shown that the CDM Einstein-de Sitter (EdS) universe is quite consistent with the WMAP data if the primordial spectrum is not scale-free. Hence, taken on their face values, the only apparent prediction made by the WMAP observations is a flat geometry, and the decelerating models like the EdS also explain these observations successfully [3].

2. $m-z$ relation in Robertson-Walker cosmologies

As the measured quantities of the SNe are the magnitude (m) and the redshift

(z), let us derive, in brief, the usual $m-z$ relation for SNe Ia in the framework of Einstein's theory, which we shall use for our analysis. The derivation assumes the simplest model of the universe based on the Robertson-Walker (R-W) metric, representing a homogeneous and isotropic spacetime. Let us assume that the observer at $r = 0$ and $t = t_0$ receives light emitted at $t = t_1$ from a SN of absolute luminosity L located at a coordinate distance r_1. The measured (apparent) luminosity l of the SN is defined by $l \equiv L/4\pi d_{\rm L}^2$, where $d_{\rm L}$, the luminosity distance, is given by

$$d_{\rm L} = (1+z)S_0\, r_1, \tag{1}$$

where $z = S(t_0)/S(t_1) - 1$ is the cosmological redshift of the SN, with S being the R-W scale factor. (Incidentally the luminosities l and L are expressed in terms of the K-corrected magnitudes m and M as $l = 10^{-2m/5} \times 2.52 \times 10^{-5}$ erg cm^{-2} s^{-1} and $L = 10^{-2M/5} \times 3.02 \times 10^{35}$ erg s^{-1}.) When written in terms of the magnitudes m and M, the above luminosity-redshift relation gets transformed into the magnitude-redshift relation:

$$m(z; \mathcal{M}, \Omega_i) = \mathcal{M} + 5\log\{H_0 d_{\rm L}(z; \Omega_i)\}, \tag{2}$$

where $\mathcal{M} \equiv M - 5\,\log_{10} H_0 +$ *constant*. The value of the *constant* depends on the chosen units in which $d_{\rm L}$ and H_0 are measured. For example, if $d_{\rm L}$ is measured in Mpc and H_0 in km s^{-1} Mpc^{-1}, then this *constant* comes out as $\approx$25. The value of r_1 appearing in (1) can be calculated by integrating the R-W metric for the SN:

$$r_1 = \begin{cases} \sin\left(\frac{1}{S_0}\int_0^z \frac{{\rm d}z'}{H(z')}\right), & \text{when} \quad k = 1 \\[2ex] \frac{1}{S_0}\int_0^z \frac{{\rm d}z'}{H(z')}, & \text{when} \quad k = 0 \\[2ex] \sinh\left(\frac{1}{S_0}\int_0^z \frac{{\rm d}z'}{H(z')}\right), & \text{when} \quad k = -1. \end{cases} \tag{3}$$

The Hubble parameter $H(z)$, appearing in these equations is provided by the Einstein field equations. If the different sources which populate the universe do not interact with each other and each of them is represented by an equation of state $\omega_i \equiv p_i/\rho_i$ (which can be a function of time in general), the Friedmann equation then yields

$$H^2(z) = H_0^2\left[\sum_i \Omega_i \exp\left\{3\int_0^z \frac{1+\omega_i(z')}{1+z'}dz'\right\} - \Omega_k\,(1+z)^2\right], \tag{4}$$

where Ω_i are, as usual, the present day energy densities of the different source components in units of the critical density $3H_0^2/8\pi G$ and $\Omega_k \equiv k/S_0^2 H_0^2$

(i denoting non-relativistic matter (m), radiation,(r), cosmological constant (Λ), quintessence (ϕ) etc.). The present value of the scale factor S_0, appearing in equations (1, 3) which measures the present curvature of spacetime, can now be calculated from

$$S_0 = H_0^{-1} \sqrt{\frac{k}{(\sum_i \Omega_i - 1)}}. \tag{5}$$

We note from equations (3, 5) that the coordinate distance r_1, and hence d_{L}, are sensitive to Ω_i for the distant SNe only. For the nearby SNe ($z << 1$), equation (2) reduces to

$$m(z) = \mathcal{M} + 5 \ \log z, \tag{6}$$

which can be used to measure $\mathcal{M}$ by using low-redshift supernovae-measurements (that are far enough into the Hubble flow so that their peculiar velocities do not contribute significantly to their redshifts).

Now for given $\mathcal{M}$, Ω_i and ω_i, these equations can provide the predicted value of $m(z)$ at any given z. We compare this value with the corresponding observed magnitude m_o and compute χ^2 from

$$\chi^2 = \sum_{j=1}^{N} \left[\frac{m(z_j;\ \mathcal{M},\ \Omega_i,\ \omega_i) - m_{o,j}}{\sigma_{m_{o,j}}} \right]^2, \tag{7}$$

where the quantity $\sigma_{m_{o,j}}$ is the uncertainty in the observed magnitude $m_{o,j}$ of the j-th SN. It may be noted that sometimes the zero-point absolute magnitudes are set arbitrarily in different data sets. While fitting the combined data set this situation is handled successfully by the constant $\mathcal{M}$ appearing in equation (7), which now plays the role of the normalization constant and simply gets modified suitably. In this case however it does not represent the usual 'Hubble constant-free absolute magnitude' but differs from the latter by an unknown constant (which is though not needed for the cosmological results). The constant $\mathcal{M}$ also takes care of the cases where the data are given in terms of the distance modulus $\mu = m(z) - M$, instead of m. Equation (7) can also be used in this case for fitting the data by using μ_o in place of m_o.

Sometimes in the data we are also provided with independent uncertainties on some another variable (say, y). In this case the equation for χ^2 gets modified as

$$\chi^2 = \sum_{j=1}^{N} \left[\frac{\{m(z_j;\ \mathcal{M},\ \Omega_i,\ \omega_i) - m_{o,j}\}^2}{\sigma^2_{m_{o,j}} + \{\frac{\partial m}{\partial y}(z_j)\}^2 \ \sigma^2_{y,j}} \right], \tag{8}$$

where $\sigma_{y,j}$ is the uncertainty in the observed variable y corresponding to the j-th SN.

The key point about the SNe Ia data-fitting is that the absolute luminosities M of all the SNe, distant or nearby, are regarded same (*standard candle*-hypothesis). Hence so is the constant $\mathcal{M}$, as it has only one extra parameter H_0 which certainly does not differ from SN to SN. Thus there are two ways of the actual data fitting: (i) estimate $\mathcal{M}$ by using equation (6) from the low-redshift SNe, and use this value in equation (2) to estimate Ω_i from the high-redshift data alone; (ii) use low-, as well as, high-redshift data simultaneously to evaluate all the parameters from equation (2) by keeping $\mathcal{M}$ as a free parameter. Obviously the second method gives a better fitting (which we have used throughout this paper).

It is obvious from equation (7) that if the model represents the data correctly, then the difference between the predicted magnitude and the observed one at each data point should be roughly the same size as the measurement uncertainties and each data point will contribute to χ^2 roughly one, giving the sum roughly equal to the number of data points N (more correctly $N-$number of fitted parameters $\equiv$ number of degrees of freedom 'dof'). If χ^2 is large, then the fit is bad. However we must quantify our judgment and decision about the *goodness-of-fit*, in the absence of which, the estimated parameters of the model (and their estimated uncertainties) have no meaning at all. An independent assessment of the goodness-of-fit of the data to the model is given in terms of the χ^2-*probability*: if the fitted model provides a typical value of χ^2 as x at n dof, this probability is given by

$$P(x,n) = \frac{1}{\Gamma(n/2)}\int_{x/2}^{\infty} e^{-u}u^{n/2-1}\mathrm{d}u. \tag{9}$$

$P(x,n)$ gives the probability that a model which does fit the data at n dof, would give a value of χ^2 as large as x or larger. If P is very small, the model is ruled out. For example, if we get a $\chi^2 = 20$ at 5 dof for some model, then the hypothesis that *the model describes the data genuinely* is unlikely, as the probability $P(20,5) = 0.0012$ is very small.

3. Fitting cosmological models to different available SNe Ia data sets

Now we have developed enough infrastructure to analyze the observations. We start our analysis with the data from Perlmutter et al. [4], which is one of the important data sets of the first generation of SN Ia cosmology programs [4, 5]. We particularly focus on the sample of 54 SNe from their 'primary fit' C. We have shown the fit-results in Table 1. The ΛCDM, as well as the models with the constant ω_ϕ have a good fit. For example the

concordance model (flat ΛCDM) has a $\chi^2 = 57.7$ at 52 dof with the *goodness-of-fit* probability $P = 27.3\%$, representing a good fit. The Einstein de Sitter (EdS) model ($\Omega_{\rm m} = 1$, $\Lambda = 0$), which used to be the favourite model before the SNe Ia observations, has a bad fit with $P = 0.06\%$. In order to take note of the history[2], we have also shown the fit to the Bondi-Gold-Hoyle steady state model (for which $m = \mathcal{M} + 5\log[z\{1+z\}]$) - the first model which predicted an accelerating universe.

The existing data points coming from a wide range of different observations were compiled by Tonry et al. [6]. With many new important additions towards higher redshifts, a refined sample of 194 SNe was presented by Barris et al. [7]. However, the data we are going to consider next, is the 'gold sample' of Riess et al. [8], which is a more reliable set of data with reduced calibration errors arising from the systematics. It contains 143 points from the previously published data, plus 14 new points with $z > 1$ discovered with the Hubble Space Telescope (HST). While compiling this sample, various points from the previously published data were discarded where the classification of the supernova was not certain or the photometry was incomplete. The fit-results of this data show that although the fits to the ΛCDM and the constant ω_ϕ-models are reasonable, they are deteriorated considerably; the probabilities P have reduced to less than half of the corresponding probabilities obtained in the case of the Perlmutter et al' data. Earlier, Roy Choudhury and Padmanabhan [9] have also shown that the Riess et al' 'gold sample' is inconsistent with a flat cosmology at 90% confidence level.

[2] A number of theories, e.g., brane cosmology, phantom cosmology, Cardassian cosmology, Chaplygin gas cosmology, have been proposed as alternatives to the standard paradigm. However either they reduce to the standard ΛCDM cosmology in the present phase of evolution or have even worse fit than the standard ΛCDM cosmology . So, they are not included in the fit.

Models	$\Omega_{\rm m}$	Ω_Λ or Ω_ϕ	ω_ϕ	$\mathcal{M}$	χ^2	dof	P
54 SNe from Perlmutter et al. (1999)							
ΛCDM (flat)	0.28 ± 0.08	$1 - \Omega_{\rm m}$	-1	23.94 ± 0.05	57.7	52	0.273
ΛCDM (n.c.)	0.79 ± 0.47	1.40 ± 0.65	-1	23.91 ± 0.06	56.9	51	0.266
cons ω_ϕ (flat)	0.48 ± 0.15	$1 - \Omega_{\rm m}$	-2.10 ± 1.83	23.91 ± 0.08	57.2	51	0.257
EdS	1	0		24.21 ± 0.03	92.9	53	0.0006
Steady State	2	0		23.78 ± 0.03	75.8	53	0.022
Gold sample of 157 SNe from Riess et al. (2004)							
ΛCDM (flat)	0.31 ± 0.04	$1 - \Omega_{\rm m}$	-1	43.34 ± 0.03	177.1	155	0.108
ΛCDM (n.c.)	0.46 ± 0.10	0.98 ± 0.19	-1	43.32 ± 0.03	175.0	154	0.118
cons ω_ϕ (flat)	0.49 ± 0.06	$1 - \Omega_{\rm m}$	-2.33 ± 1.07	43.30 ± 0.04	173.7	154	0.132
EdS	1	0		43.58 ± 0.02	324.7	156	10^{-13}
Steady State	2	0		43.15 ± 0.02	318.3	156	10^{-13}
164 SNe from Gold + ESSENCE (Krisciunas et al. 2005)							
ΛCDM (flat)	0.30 ± 0.04	$1 - \Omega_{\rm m}$	-1	43.34 ± 0.03	190.3	162	0.064
ΛCDM (n.c.)	0.48 ± 0.10	1.04 ± 0.18	-1	43.32 ± 0.03	187.2	161	0.077
cons ω_ϕ (flat)	0.50 ± 0.06	$1 - \Omega_{\rm m}$	-2.69 ± 1.30	43.29 ± 0.04	185.5	161	0.091
EdS	1	0		43.60 ± 0.02	348.2	163	10^{-15}
Steady State	2	0		43.15 ± 0.02	331.1	163	10^{-13}
168 SNe from Gold + ESSENCE + 4 SNe from Clocchiatti et al. (2005)							
ΛCDM (flat)	0.29 ± 0.04	$1 - \Omega_{\rm m}$	-1	43.35 ± 0.03	200.8	166	0.034
ΛCDM (n.c.)	0.51 ± 0.09	1.12 ± 0.16	-1	43.32 ± 0.03	195.8	165	0.051
cons ω_ϕ (flat)	0.50 ± 0.04	$1 - \Omega_{\rm m}$	-3.18 ± 1.46	43.28 ± 0.04	193.4	165	0.065
EdS	1	0		43.61 ± 0.02	367.5	167	10^{-17}
Steady State	2	0		43.16 ± 0.02	338.3	167	10^{-13}
Gold sample + 4 SNe from Clocchiatti et al. (2005)							
ΛCDM (flat)	0.30 ± 0.04	$1 - \Omega_{\rm m}$	-1	43.35 ± 0.03	188.0	159	0.058
ΛCDM (n.c.)	0.49 ± 0.10	1.07 ± 0.17	-1	43.32 ± 0.03	184.2	158	0.075
cons ω_ϕ (flat)	0.50 ± 0.05	$1 - \Omega_{\rm m}$	-2.95 ± 1.41	43.29 ± 0.04	182.1	158	0.092
EdS	1	0		43.60 ± 0.02	345.0	160	10^{-15}
Steady State	2	0		43.16 ± 0.02	325.6	160	10^{-13}

Table 1. Fits of different cosmologies to available data sets: some models have been constrained by the requirement of a flat space ($\Omega_{\rm m} + \Omega_\phi = 1$), whereas the rest have no constraint (n.c.).

We now consider the first results of the ESSENCE project [10] (made public in August 2005) under which 9 SNe with redshift in the range 0.5 -

0.8 were discovered jointly with HST and Cerro Tololo 4-m telescope. In order to minimize the systematic errors, all the ground-based photometry was obtained with the same telescope and instrument. We consider 7 SNe of this project which have unambiguous redshift and definite classification, and add them to the 'gold sample' resulting in a reliable sample of 164 SNe. The Table 1 shows that the fits to different cosmologies have further worsened considerably and do not represent a good fit, in any case. Increasing the number of fitted parameters (for example, in the models with a constant ω_ϕ) improves the fit marginally only.

Next we consider the recent discovery of 5 SNe at redshift $z \approx 0.5$ by the High-z Supernova Search Team [11] (results made public in October 2005). We consider 4 SNe from this sample for which distances estimated from the MLCS2k2 (Multi-colour Light Curve Shape) method are available, so that we can include them in the previous sample of 'gold + ESSENCE' which also use the MLCS2k2 method to determine the distance moduli. The fit-results of the resulting sample of 168 SNe are very disappointing. The quality of the fits to different models has deteriorated to such an extent that the concordance model can be rejected at 96.6 % confidence level! This is an alarming situation. Other models have marginally similar fit and increasing the number of fitted parameters does not help significantly. Models with variable $\omega_\phi(t)$ do not help either. For example, if we consider $\omega_\phi(z) = \omega_0 + \omega_1 \; z/(1+z)$ with ω_0, ω_1 as constants, we obtain $\Omega_{\rm m} = 0.42$, $\Omega_\phi = 0.42$, $\omega_0 = -4.95$ and $\omega_1 = 2.83$ as the best-fitting solution with $\chi^2 = 193.07$ at 163 dof and $P = 5.4\%$ (in fact, the model is very degenerate in this case and the parameters wander around near the minimum χ^2 in a flat valley of some complicated topology).

It has been mentioned that the ESSENCE data are affected by the selection bias which can affect their cosmological use [10]. However, we do not find any such effect from the fitting, as is clear from the Table. We notice that the parameters and their uncertainties estimated by using the ESSENCE sample are absolutely consistent with those from the use of gold sample or the gold+Clocchiatti et al.'s sample; and we do not find any smoking gun pointing out that this sample is completely different from the others. However, even if we exclude the ESSENCE sample from the fit, the concordance model is still ruled out at more than 94% confidence level.

Finally we consider the recently published (made public in October 2005) first year-data of the planned five-year SuperNova Legacy Survey (SNLS) [12]. However, the SNLS data have been analyzed in a different way than the other data sets we considered earlier and it does not make sense to add them for a joint analysis. Hence we limit ourselves to commenting on the way SNLS data have been analysed.

In the SNLS, the authors claim to have achieved high precision from improved statistics and better control of systematics by using the multi-band rolling search technique and a single imaging instrument to observe the same fields. Their data set includes 71 high redshift SNe Ia in the redshift range 0.2 - 1 from the SNLS, together with 44 low redshift SNe Ia compiled from the literature but analyzed in the same manner as the high-z sample. As the SNLS data have been analyzed differently, the fitting procedure followed by the authors is also different. In order to calculate χ^2, they use

$$\chi^2 = \sum_{j=1}^{N} \left[\frac{\{\mu(z_j;\ \mathcal{M},\ \Omega_i) - \mu_{o,j}\}^2}{\sigma^2_{\mu_{o,j}} + \sigma^2_{\rm int}} \right], \tag{10}$$

where $\sigma_{\rm int}$, is the (unknown) intrinsic dispersion of the SN absolute magnitude which, *unlike the other data sets*[3], is not included in the σ_{μ_o}; rather it has been used as an adjustable free parameter to obtain $\chi^2/{\rm dof} = 1$. We shall return to this issue later for our comments. First we want to verify if we can reproduce the results of Astier et al. from equation (10) by using their calculated μ_o (given in columns 7 of their Tables 8 and 9) instead of using their 'stretch' and 'color' parameters, which do not seem necessary once we have μ_o. We find that by fixing $\sigma_{\rm int} = 0.13$, we get $\Omega_{\rm m} = 1 - \Omega_\Lambda = 0.26$, $\mathcal{M} = 43.16$ with $\chi^2/{\rm dof} = 1.00$; and $\Omega_{\rm m} = 0.31$, $\Omega_\Lambda = 0.81$, $\mathcal{M} = 43.15$ with $\chi^2/{\rm dof} = 1.01$. This is exactly what Astier et al have obtained.

The intrinsic dispersion in the absolute magnitude of SN Ia (combined with dust extinction of the host galaxy) can be estimated only statistically (unlike the photometric error, which can be estimated from the photometry of the individual SN Ia). Unfortunately we do not have a reliable way to estimate dust extinction or pure intrinsic dispersion of SNe Ia separately. However, the introduction of $\sigma_{\rm int}$ in equation (10) is justified only when we use independent measurement uncertainties $\sigma_{\rm int,j}$ on the parameter (as we have mentioned earlier in equation (8)), instead of using it as a free parameter. The latter case is just equivalent to increasing the error bars suitably in order to have a desired fit. In this way one can fit any model to the data. For example, the EdS model can also have a similar fit by considering $\sigma_{\rm int} = 0.258$: $\mathcal{M} = 43.46$ with $\chi^2/{\rm dof} = 1.00$. This shows that the approach does not have any predictive power. One could choose the variable $\omega_\phi(z)$ such that it gives a lower $\chi^2/{\rm dof}$ with the same $\sigma_{\rm int} = 0.13$. Also, for a similar $\sigma_{\rm int}$, one can obtain a reasonable value of the reduced χ^2 for another model. For example, increasing $\sigma_{\rm int}$ only to $\sigma_{\rm int} = 0.16$, the model

[3] It should be noted that all the other observations, we have considered before, already include the intrinsic dispersion of the SN absolute magnitude in their error bars σ_{m_o} or σ_{μ_o}, which has been estimated by reasonable methods

$\Omega_{\rm m} = 0$, $\Omega_\phi = 0$ gives χ^2/dof =0.86. However, one cannot physically test the viability of the model so that one can take any decision. This happens because the present approach (which simply assumes, rather than tests, that the data have a good fit to the model) prohibits an independent assessment of the goodness-of-fit-probability P, in the absence of which the estimated parameters do not have any significance. All one can do, with the present approach, is that one can compare the goodness-of-fit of different models. For example, with $\sigma_{\rm int} = 0.13$, the EdS model has a worse fit than the ΛCDM model, giving $\chi^2/\text{dof} = 2.7$. In this context, it would be remarkable that the results of the SNLS data are consistent with a flat geometry whereas the best-fit values of the other observations give a larger value of the $\Omega_{\rm total}$.

4. Conclusion

Supernovae Ia observations have profoundly changed cosmology by predicting an accelerated rate of cosmic expansion, and thus a repulsive dark energy component - an issue which is regarded as an almost mature science now. However, as more and more accurate data get accumulated, thanks to the remarkable progress made in various types of astrophysical and cosmological observations in recent years, they do not seem to fit any cosmology. The recent observations, taken at their face values, seem to rule out all the cosmologies at fairly high confidence levels. Though these probabilities may not be regarded sufficient to rule out the models completely, however, they are high enough to point out towards the alarming trend of the recent data: as you add newer data to the older samples, the goodness-of-fit-probability from the resulting samples successively decreases. Though the fit improves in some cases if we do not stick to the concordance model, however, this is inconsistent with the anisotropy measurements of CMB which predict a flat space.

The recently made SNLS observations by the Supernova Legacy Survey [12] are analyzed in a different way. While the other observations estimate the intrinsic scatter in the absolute magnitude $\sigma_{\rm int}$ from the nearby data, the SNLS estimates it from all the observed data. For this purpose, $\sigma_{\rm int}$ is considered as a free parameter to be estimated from all the data by requiring that it gives a good fit. Obviously, this data is not suitable for a goodness-of-fit analysis. It must be noted that our result (that the recent observations seem to rule out all the cosmologies at fairly high confidence levels) is deduced from those observations only which, unlike the SNLS data, have already included $\sigma_{\rm int}$ in their error bars.

Assuming that the standard big bang cosmology is correct, the present situation is pointing out towards some flaws in our understanding of the SN Ia phenomenon and towards the futility of the use of SNe Ia in order to

constrain cosmological models. We need better understanding of the entire SN Ia phenomenon in order to test the empirical calibrations that are so confidently extrapolated at high redshifts. Similar conclusions have also been drawn by Clocchiatti et al. [11] from a smaller sample of data. However, this is more evident from the present analysis of a bigger sample of data. This view is also supported by Middleditch [13] who argues that SNe Ia seem to be affected by some systematic effects which alone, without invoking any dark energy, could make them too faint for their redshifts. It is argued that it may be impossible to get a clean sample of SNe Ia which are free from this kind of effects [14].

This reminds us of a similar story of the $m-z$ test for galaxies in 1970s - it was agreed upon finally that uncertain evolutionary effects tend to dominate at high redshifts. Though most studies confirm that the luminosity properties of SNe Ia at different redshift and environments are similar [4, 15], however, there are other theoretical studies which have found variations indicating evolutionary effects [16]. It has been shown by Drell et al. [17] that the peak luminosities estimated for individual SNe Ia by two different methods are not entirely consistent with one another at high redshifts, $z \sim 0.5$. If evolution was entirely absent, the differences between them should not depend on redshift. They further showed that the three luminosity estimators in practice (the multicolor light curve shape method, the template fitting method, and the stretch factor method) reduce the dispersion of distance moduli about best fit models at low redshift, but they do not at high redshift, indicating that the SNe have evolved with redshift. This view is also corroborated by some recent observations which may go against the 'standard candle'-hypothesis of SNe of type Ia, we mention the following two:

1. SNLS-03D3bb, which is a recently observed high redshift ($z = 0.244$) type Ia SN with extreme unusual features and no obvious analogue at low redshifts. It does not obey the usual lightcurve shape-luminosity relationship for SNe Ia that allows them to be calibrated as standard candles [18].

2. Observations of two supernova remnants DEM L238 and DEM L249 made with the *Chandra* and *XMM-Newton* X-ray satellites in the *large Magellanic cloud* [19] may also be mentioned. While the presence of Fe-rich gas at the centres of these objects suggests that they are remnants of type Ia supernova explosions, the standard model of type Ia supernova remnants cannot explain the presence of relatively dense supernova ejecta with long ionization timescales.

We may recall that in the 1970s-80s astronomers tried to fit number

counts of radio sources to cosmological models and improved the fit by adding multi-parameter evolutionary functions like luminosity evolution, number density evolution, etc. This gave interesting possibilities of evolution though had no predictive value for the model. One can do similar exercise to improve the fit of the SNe Ia, particularly by keeping the dark energy equation of state parameter $\omega_\phi(z)$ completely free as a function of z.

Note added in the proof: It may be mentioned that a more recently made observation [20] claims improvements in the data and provides better fits to the cosmological models. However, this sample does not include the ESSENCE data [10] in the analysis, and hence our analysis is still meaningful.

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